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Assessment of Atmospheric Pollution Around Mangalore, West Coast of India

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by

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Introduction

This synopsis concerns about the PhD thesis work carried out on the influence of atmospheric inputs and impact of atmospheric pollution on the monsoon-dominated region, around Mangaluru, south-west coast of India. This study involved the fortnightly variations in the deposition of atmospheric dust, the composition of the water-soluble fraction the dust and rainwater of sampling monitoring stations of the pristine, urban and industrialized regions in the area of investigation. The dissolved composition refers to the water-soluble fraction of the rainwater and dust of parameters, such as nutrients and, major ions and trace elements. The implications of the study discussed in terms of not only on the health of the coastal ecosystem but also on the primary productivity of the south-eastern Arabian Sea. In addition, a comparison has been made to understand the relative variations of atmospheric and riverine inputs to the marine environment along the south-west coast of India.

Quantification of atmospheric inputs is estimated based fallout of dust/dry deposition as well as through the scavenging process by the rainfall. Additionally, the particle size of the above-mentioned types has been measured which is an important indication about the sources of particles in the atmospheric compartment. For instance, particles in the atmosphere originate from seawater as sea-salt aerosols due to the action of wind, re-suspension of soil, biomass burning, volcanic emission, as well as various types of anthropogenic activities such as fossil fuels combustion, and refining and industrial processing of metals and chemicals, etc. (Berner and Berner, 1996), they will be finally added to terrestrial and aquatic environments, through wet as well as dry deposition, and especially very fine nanoparticles often eventually to accumulate in the human body as pollutant (Willeke and Whitby, 1975; Berner and Berner, 1996; Hofman et al., 2017; Suvarapu et al., 2017; Kumar et al. 2019; Gonet and Maher, 2019; Yang et al., 2019; Zan et al., 2019). The relative proportion of these may vary in the composition as well as quantity, often causing health hazards (Zan et al., 2019). Increase in the concentrations of atmospheric particles alter radioactive heat balance on earth, microphysical properties of clouds, and alter the rainfall trends (Ramanathan et al., 1989; 2001; Boucher et al., 2013; Bahadur et al., 2012; Soni et al., 2016). Therefore, the particle size distribution of the dust and rainwater has been measured as supporting evidence to trace the sources of dust in

this work. When the particles from the above-mentioned sources are liberated into the atmosphere, there will be segregation of particles, for instance, the sea salt and mineral dust. Aerosols are generally grouped into four different sized fractions (0.05–0.63 μm, 0.63–1.26 μm, 1.26–2.5 μm, and 2.5–10 μm), whereas, those from industrial processing, fossil fuel and biomass burning/forest fire are grouped into fine particles range (radius < 0.63 μm; Willeke and Whitby, 1975; Feng et al., 2013). Since the atmospheric particles, including the smoke, are in the wide size range, the finer particles are hazardous not only to humans but also to the biotas as well as climate (Kaufman et al., 2005; Satheesh et al., 2008; Kaskaoutis et al., 2011; Rosenfeld et al., 2014; Warrier et al., 2014; Gune et al., 2016; Gonet and Maher, 2019). During the transportation processes of atmospheric particles, there is a tendency in the decrease of coarser particles with distance from the source due to gravitational settling (Mahowald et al., 2014; Denjean et al., 2016a,b). Nevertheless, the atmospheric particles, especially those derived from deserts, like the Sahara are often supply beneficial nutrients and trace elements to the forest as well as to the marine environment (Duce et al., 1991; Spokes et al., 1994; Turner,1996; Jickells et al., 2005; Prospero et al., 1999; Jickells and Moore, 2015; Pabortsava et al., 2017). However, in the dust proximity of the Arabian Sea, modelling study shows that the excess of iron deposition often leads to a drastic reduction of primary productivity (~ 50%), particularly during the summer season (Guieu et al., 2019).

1.1 **Background information**

The Northern Indian Ocean (NIO) is one of the high anthropogenic impact centres in the global ocean. There are two branches of this ocean: The north-western branch is the Arabian Sea, which is characterised by the dominance of deserts, while, the north-eastern branch is the Bay of Bengal, dominated by the inputs from world's major rivers. The seasonal reversal atmospheric circulation, as well as the ocean circulation, takes place due to difference in the heating of land and the ocean during the summer and winter seasons (McCreary et al., 2009). This is due to the blockage of the northern branches of the Indian Ocean by land, unlike for the Atlantic and the Pacific Ocean. This is the main cause for the difference in the semi-annual heating of land and ocean leading to the semi-annual reversal wind patterns with an intense during summer and winter seasons.

1.2 Review of literature

The literature review has been carried out in the thesis is based on visits to some of the libraries as well as in our institute, information gathers through the internet along with literature provided by our research guide. The precipitation is minimally affected by anthropogenic activity among the examined water samples, and evaporation is the main factor controlling the enrichment of dissolved salts. The overlapping $\delta^{34}S$ values of sulphate in rainwater and groundwater reveal that the sulphate traced mainly from air pollution (Liu, et al., 2013).

Acidification of rain-water is identified as one of the most serious environmental problems of trans-boundary nature. Acid rain is mainly a mixture of sulphuric and nitric acids depending upon the relative quantities of oxides of sulphur and nitrogen emissions. Such changes in the soil chemical characteristics reduce soil fertility, which ultimately causes a negative impact on the growth and productivity of forest trees and crop plants. Acidification of water bodies causes large scale impact on aquatic organisms including fishes. Acidification has adverse effects on plants, human health, damages man-made materials and structures (Rodhe, 1988; Rodhe et al., 1995). According to Hegde (2007) industrial and urban locations are generally polluted with trace elements than rural as well as suburban areas, due to anthropogenic sources. Anthropogenic activities release fine aerosols particle into the atmosphere. They enhance scattering and absorption of solar radiation, decrease the density of clouds that reduce precipitation. (Ramanathan et al., 2001).

Nitrogen is the major nutrient in the terrestrial ecosystem and marine environment. Excess of this nutrient concentration affects the catalytic property of the troposphere, Earth's radiation budget, acidification of ecosystems, and causes eutrophication of lakes, estuaries and coastal oceanic regions (Galloway, 1995).

Higher concentrations aerosols in the atmosphere of the northern hemisphere, particularly noticed during winter months – (November to February) explained as due to dry climate than during the summer season. The inter-relationships of major inorganic species of nutrients, especially nitrogen, potassium, point to biomass burning and anthropogenic emissions as the dominant sources of and SO_4^{2-} and NO_3^- in rain and aerosols (Rodhe and

Herrera, 1988; Jickells et al., 2013, 2017). The contribution of NO3- from dust seems to be insignificant, while NH_4^+ is from anthropogenic activity appears to be transported in the gaseous phase. The inorganic deposition nitrogen seems to be dominant in the Arabian Sea. (Rastogi and Sarin, 2007). Mineral dust produced in Asia mainly from arid and semi-arid regions may often contain a significant proportion of dissolved ions (Dentener et al., 1996).

1.3 Area of Investigation

The area of investigation is the southern part of the west coast of India, near Mangalore (Fig. 1). This region is quite large coastal plain along the south-west coast of India, having a maximum width of about 70 km (Radhakrishna and Vaidyanadhan, 1994), cover an area about 8000 km^2. The area of study is under quite rapid development in terms of industrialization as well as urban agglomeration. There are about 10 large-scale, 40 medium-scale and nearly 9000 small-scale industries functioning in the area, particularly near New Mangalore – Baikampady Industrial Estate. Many of these industries often emit pollutants. Some of the important major industries are Mangalore Refineries and Petrochemicals Limited, Mangalore Chemicals and Fertilisers Limited, Kudremukh Iron Ore Company, Mangalore Chemicals and Fertilizers, Canara Steels, etc. Automobile pollution perhaps seems to be significant in contributing a lot to the total suspended particulate matter, oxides of sulphur and nitrogen to theatmosphere.

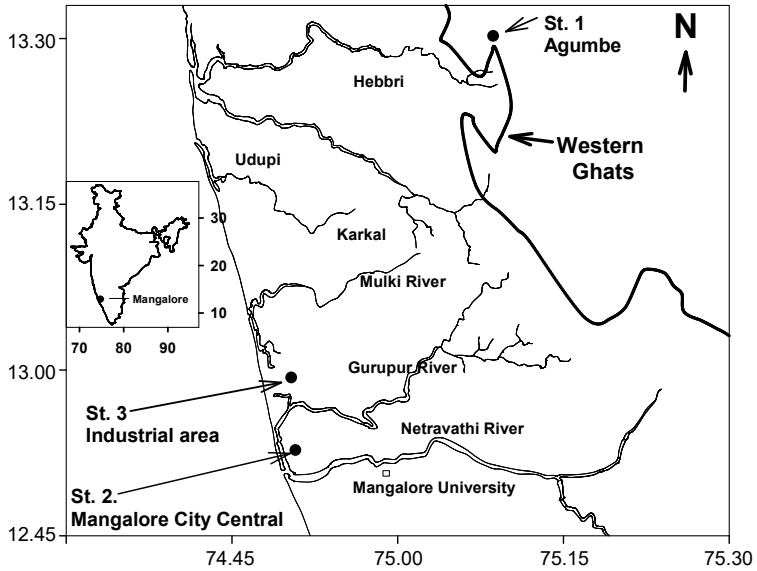

Figure 1. Map of the study area showing sample monitoring stations along the south-west coast of India.

This study area is under the tropical monsoon type of climate as per the Koppen's classification, characterized by high rainfall during summer with an average temperature between 27°C and 34°C. The humidity and rainfall are particularly high during the summer season as compared to the winter season. The quantum of annual rainfall increases over the west coast of India from 200 cm yr^{-1} to more than 500 cm yr^{-1} over the Western Ghats. About 86 to 93% of the annual rainfall in the coastal region of the study area received during the southwest monsoon season. The amount of rainfall over Agumbe, the peak of the Western Ghats, receives the highest rainfall in the area of investigation (744 ± 114 cm yr^{-1}) with a peak during the summer monsoon season (84.00 to 98.98% of the annual average; Manjunatha et al., 2015).

There are three atmospheric sample monitoring stations selected for this study (Fig. 1): Station 1: Agumbe – the peak of the Western Ghats in the study area that receives one of the high rainfall regions in Peninsular India. This station is considered as the background station for understanding the human impacts on the atmosphere in the study area. In order to know the impact of anthropogenic activity in the study area, a high raised building (about 30 m from ground level) - the University Medical Centre, Mangalore City Centre region, and another building of height about 20 m in the industrial area – Baikampady have been selected.

1.4 Objectives

The main objectives of the study are to:

- estimate fortnightly variations in the deposition of atmospheric dust from the atmospheric compartment and its implications to the coastal Arabian Sea;
- determine sources of dust in the atmospheric compartment and distinguish between natural and human-made fluxes of both local and regional anthropogenic activities to the Eastern Arabian Sea;
- determine the episodic input of dust from the atmospheric compartment to the coastal ocean; and
- quantify relative magnitudes of atmospheric and riverine fluxes to the south-west coast of India and their implications on the marine environment.

To achieve these objectives, samples of rainwater and dust fallout were collected at a fortnightly interval over a period of nearly three years from 2013. The geochemical investigation on rainwater

and water-soluble dust of different monitoring stations provide feedback about the extent of anthropogenic activities on the atmospheric chemistry as well as on the adjacent marine environment. Samplers for the bulk precipitation collection were installed on the terrace of the buildings (10-30m above the ground). Major ions and some of the trace elements measured by using standard procedures. The data generated will be processed by using multivariate statistical analysis to identify the atmospheric processes with human impacts occurring in the study region and their effect on the marine environment.

1.5 Outline of the thesis

The thesis is prepared as seven chapters. The criteria of classifying chapters have been based on compositional variation with seasons, types of samples and chemical analytical procedures followed in addition to statistical techniques:

Chapter 1: Introduction

This chapter provides an overview of the current understanding of the atmospheric chemical processes and their impacts and inputs to the terrestrial and marine regions are discussed. Here, overviews of the global review along with the regional and local research carried out are discussed to identify the work to be done in the area of study with the following objectives of the thesis. In addition, information about the intention of anthropogenic assessment of atmospheric pollution is discussed based on the comparison of results from the relatively pristine region with urban and industrial anthropocentric regions of the study area, and implications on the marine productivity.

Chapter 2: Materials and Methods

This chapter provides details of protocol followed during the collection of samples, and criteria for selecting, the sampling stations, sampling procedure, pre-treatment and details of methods. By using bulk precipitation collectors, atmospheric samples were collected at three stations mentioned earlier, at fortnightly to monthly intervals from 2013 to 2015. Samples of the bulk precipitation collected were filtered by using Millipore cellulose acetate membrane filters (0.45 μm pore size). After filtration, a part of samples was used for measuring

physicochemical parameters, such as pH and electrical conductivity. The remaining samples were split into two parts; to one half, thymol preservative added for the measurement of major ions by ion chromatography and to another half, samples were acidified with ultra-pure nitric acid for trace elemental analysis by ICP MS. The data so obtained were statistically analysed to simplify the results to draw meaningful conclusions.

The laser-diffraction particle size analysis was performed for rain and dust samples by using Sequoia LISST-PORTABLE|XR. One of the factors determines the radiative heat balance on earth is the composition and concentration of particles in the atmosphere. Movement of atmospheric particles depends also on the size, density and wind velocity. Generally, the fine particles in the atmosphere originate from the dry soil that easily erodes maximum during dry season plays an adverse effect not only on climate but also on human's health. Similarly, the climate is affected by major gases, like nitrogen, carbon and oxygen.

Some representative samples analysed for mineral identification by x-ray diffraction (Rigaku Miniflex 600 diffractometer) by using Cu-Kα (λ=1.5418 Å), the operating voltage of 40 kV and a current of 15 mA. The diffraction angle scanned were in the range 2θ=3◦ to 60◦. A few samples were analyzed by SEM-EDX to determine the grain morphology and composition. The SEM-EDX analysis was carried out by using a computer-controlled field emission scanning electron microscope SEM (Zigma Field Emission Scanning Electron Microscope CALRS ZEISS). The vacuum dried samples were mounted on metal stubs and coated gold with the help of Sputter Coater to make samples electrically conductive for identification. A large amount of data generated in this study is discussed in the following chapters with the summary and conclusions at the end part of the thesis.

Chapter 3: Deposition of atmospheric particles

This chapter provides an overview of the techniques adopted the quantification of the deposition of atmospheric particles those scavenged by the rain and dust fallout from dry depositional processes. This has been achieved through the collection of samples at fortnightly to monthly intervals over a period of nearly three years. The dry dust deposition and through rainfall, as well as satellite data are used to compare and validate the results. In addition, efforts have been made to delineate episodic input of atmospheric particles to the area of investigation.

Chapter 4: Composition of atmospheric particles and their fluxes to the Eastern Arabian Sea.

In this chapter, the water-soluble fraction of atmospheric particles is studied to distinguish between natural and human-made fluxes, from local and regional atmospheric inputs to the Eastern Arabian Sea. Here, the emphasis in the temporal and spatial variability of various water-soluble major ions, nutrients and contaminants present in the atmospheric particles. The data used in this chapter are the water-soluble proportion of major ions, trace elements, and nutrients, and clay mineralogy, SEM and ED XRF for some representatives of dust and rainwater samples.

Chapter 5: Relative variations of atmospheric and riverine fluxes to the Eastern Arabian Sea.

In this chapter, the temporal and spatial variability of atmospheric particles and rainwater have been used with relevant fluxes data to quantify the amount of the measured parameters introduced from atmospheric and riverine compartments to the marine environment. Their implications of the processes operating at the land-ocean interaction zone are discussed with regards to atmospheric input to the open ocean.

Chapter 6: Factors governing the composition of atmospheric particles

As there are three atmospheric monitoring stations selected for this investigation, the large numbers of samples have been collected and measured for particle size, major ions, trace elements; it is often difficult to discuss each one of these groups of parameters. In order to reduce data description and also to avoid repetition, statistical data reduction techniques, like principal component analysis has been performed. This indeed helped to understand and simplify the factors of the complex atmospheric interaction processes operating in the area of investigation.

Chapter 7: Summary and Conclusions

This chapter provides a summary of the data, results, discussion with conclusions of the comprehensive data generated in this thesis work. The importance of atmospheric inputs in the form of

atmospheric particles, in the high rainfall region of the tropical south-west coast of India has been attempted. Implications of these are discussed in terms of human impacts on climate and primary productivity in the Eastern Arabian Sea.

After the summary and conclusions, a list of references cited in the thesis is provided, followed by acknowledgements.

Bibliography

Bahadur, R., Praveen, P. S., Xu, Y., and Ramanathan, V. (2012) Solar absorption by elemental and brown cabon determined from spectral observations, P. Natl. Acad. Sci. USA, 109, 17366–17371, doi:10.1073/pnas.1205910109.

Berner, E.K., Berner, R.A., 1996 The Global Water Cycle: Geochemistry and Environment. Prentice-Hall Inc., N.J., 397p.

Boucher, O., Randall, D., Artaxo, P., Bretherton, C., Feingold, G., Forster, P., Kerminen, V.M., Kondo, Y., Liao, H., Lohmann, U., Rasch, P., Satheesh, S. K., Sherwood, S., Stevens, B., and Zhang, X. Y., (2013). Clouds and aerosols; In: Climate change 2013: The physical science basis. Contributions of working group I to the fifth assessment report of the intergovernmental panel on climate change (eds) Stocker T F, Qin D, Plattner G-K, Tignor M, Allen S K, Boschung J, Nauels A, Xia Y, Bex V and Midgley P M, Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 571–658, https://doi.org/10.1017/ CBO9781107415324.016.

Denjean, C., Cassola, F., Mazzino, A., Triquet, S., Chevaillier, S., Grand, N., Bourrianne, T., Momboisse, G., Sellegri, K., Schwarzenbock, A., Freney, E., Mallet, M., and Formenti, P. (2016) Size distribution and optical properties of mineral dust aerosols transported in the western Mediterranean, Atmos. Chem. Phys., 16, 1081–1104, doi:10.5194/acp-16-1081-2016, 2016a.

Denjean, C., Formenti, P., Desboeufs, K., Chevaillier, S., Triquet, S., Maillé, M., Cazaunau, M., Laurent, B., Mayol-Bracero, O. L., Vallejo, P., Quiñones, M., Gutierrez-Molina, I. E., Cassola, F., Prati, P., Andrews, E., and Ogren, J. (2016) Size distribution and optical properties of African mineral dust after intercontinental transport, J. Geophys. Res.-Atmos., 121, 7117–7138, doi:10.1002/2016JD024783, 2016b.

Dentener, F.J., Carmichael, G.R., Zhang, Y., Lelieveld, J., Crutzen, P.J., 1996. Role of mineral aerosol as a reactive surface in the global troposphere. Journal of Geophysical Research vol., 101, pp. 22869–22889.

Duce, R. A., Liss, P. S., Merrill, J. T., Atlas, E. L., Buat-Menard, P., Hicks, B. B., Miller, J. M., Prospero, J. M., Arimoto, R., Church, T. M., Ellis, W., Galloway, J. N., Hansen, L., Jickells, T. D., Knap, A. H., Reinhardt, K. H., Schneider, B., Soudine, A., Tokos, J. J., Tsunogai, S., Wollast, R., and Zhou, M. (1991) The atmospheric input of trace

species to the world ocean, Global Biogeochemical Cycles, 5, 193–259, 10.1029/91GB01778.

Feng, Y., Ramanathan, V., & Kotamarthi, V. R. (2013). Brown carbon: a significant atmospheric absorber of solar radiation? Atmospheric Chemistry and Physics, 13(17), 8607–8621. doi:10.5194/acp-13-8607-2013.

Galloway, J.N., (1995). Acid Deposition: Perspectives in Time and Space. Water, Soil and Air Pollution 85: 15-24.

Gonet, T., and Maher, B.A., (2019). Airborne, vehicle-derived Fe-bearing nanoparticles in the urban environment – A review. Environmental Science &Technology. doi:10.1021/acs.est.9b01505, 2019.

Guieu, C., Al Azhar, M., Aumont, O., Mahowald, N., Levy, M., Ethé, C., & Lachkar, Z. (2019). Major impact of dust deposition on the productivity of the Arabian Sea. Geophysical Research Letters. doi:10.1029/2019gl082770.

Gune, M., Harshavardhana, B.G., Balakrishna, K., Udayashankar, H.N., Shankar, R., Manjunatha, B.R., (2016). Rock magnetic finger-printing of soil from a coal-fired thermal power plant". Environmental Monitoring and Assessment 188, pp. 1-13.

Hegde, P., (2007). Major Ionic Composition of Aerosol, Rainwater and its Impact on Surface and Sub-surface Waters, in and Around Mangalore, West Coast of India Environ Monit Assess 133:119–125.

Hofman, J., Maher, B.A., Muxworthy, A.R., Wuyts, K., Castanheiro, A., Samson, R., (2017). Biomagnetic monitoring of atmospheric pollution: A review of magnetic signatures from biological sensors. Environ. Sci. Technol., 51, 6648–6664.

Jickells, T. D., An, Z. S., Andersen, K. K., Baker, A. R., Bergametti, G., Brooks, N., Cao, J. J., Boyd, P. W., Duce, R. A., Hunter, K. A., Kawahata, H., Kubilay, N., La Roche, J., Liss, P. S., Mahowald, N., Prospero, J. M., Ridgwell, A. J., Tegen, I., and Torres, R. (2005). Global Iron Connections Between Desert Dust, Ocean Biogeochemistry, and Climate, Science, 308, 67-71, 10.1126/science.1105959.

Jickells, T. D., Baker, A. R., Cape, J. N., Cornell, S. E., and Nemitz, E., 2013 .The cycling of organic nitrogen through the atmosphere *Phil. Trans. R. Soc. B* **368** 20130115.

Jickells, T. D., et al. (2017), A reevaluation of the magnitude and impacts of anthropogenic atmospheric nitrogen inputs on the ocean, Global Biogeochem. Cycles, 31, 289–305, doi:10.1002/ 2016GB005586.

Jickells, T., Moore, C.M., 2015.The importance of atmospheric deposition for ocean productivity. Ann Rev Ecol Evol Syst. 2015;46:481–501.

Kaskaoutis, D. G., Kharol, S. K., Sinha, P. R., Singh, R. P., Kambezidis, H. D., Sharma, A. R., and Badarinath, K.V.S., (2011). Extremely large anthropogenic-aerosol contribution to total aerosol load over the Bay of Bengal during the winter season; Atmos. Chem. Phys. 11 7097–7117, https://doi. org/10.5194/acp-11-7097-2011.

Kaufman, Y. J., Koren, I., Remer, L. A., Rosenfeld, D., and Rudich, Y., (2005). The effect of smoke, dust, and pollution aerosol on shallow cloud development over the Atlantic Ocean; Proc. Natl. Acad. Sci. 102(32) 11,207–11,212, https://doi.org/ 10.1073/pnas.0505191102.

Kumar, S., Prasad, S., Yadav, K. K., Shrivastava, M., Gupta, N., Nagar, S., Malav, L. C. (2019). Hazardous heavy metals contamination of vegetables and food chain: Role of sustainable remediation

approaches-Areview.Environmenta Research, 108792. doi:10.1016/ j.envres.2019.108792.

Liu, Q., A. P. Roberts, J. C. Larrasoaña, S. K. Banerjee, Y. Guyodo, L. Tauxe, and F. Oldfield, 2013. ironmental IPCC. Climate Change 2013: Te Physical Science Basis. Contribution of Working Group I to the Fifh Assessment Report of the Intergovernmental Panel on Climate Change, [Stocker, T. F. et al. (ed.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.

Mahowald, N., Albani, S., Kok, J. F., Engelstaeder, S., Scanza, R., Ward, D. S., and Flanner, M. G. (2014). The size distribution of desert dust aerosols and its impact on the Earth system, Aeolian Res., 15, 53–71, doi:10.1016/j.aeolia.2013.09.002.

Manjunatha, B. R., Balakrishna, K., Krishnakumar, K. N., Manjunatha, H. V., Avinash, K., Mulemane, A. C., & Krishna, K. M., (2015). Increasing trend of rainfall over Agumbe, Western Ghats, India in the scenario of global warming. The Open Oceanography Journal, 8(1).

McCreary, J., R. Murtugudde, J. Vialard, P. Vinayachandran, J. D. Wiggert, R. R. Hood, D. Shankar, and S. Shetye, (2009). Biophysical processes in the Indian Ocean, in Indian Ocean Biogeochemical Processes and Ecological Variability, AGU, Washington, D.C. pp. 9–32.

Pabortsava, K., Lampitt, R. S., Benson, J., Crowe, C., McLachlan, R., Le Moigne, F.A.C., Woodward, E.M.S. (2017). *Carbon sequestration in the deep Atlantic enhanced by Saharan dust. Nature Geoscience, 10(3), 189–194.* doi:10.1038/ngeo2899.

Prospero, J. M., (1999). Long-range transport of mineral dust in the global atmosphere: Impact of African dust on the environment of the southeastern United States, Proceedings of the National Academy of Sciences, 96, 3396–3403, 10.1073/pnas.96.7.3396.

Radhakrishna, B.P., and Vaidyanathan, R., (1994) Geology of Kamataka. Geological Society of India. Bangalore, 298p.

Ramanathan, V., Cess, R. D., Harrison, E. F., Minnis, P., Barkstrom, B .R., Ahmad, E., and Hartmann, D., (1989). Cloud-radiative forcing and climate: Results from the earth radiation budget experiment; Science 243(4887) 57–63, https://doi.org/10.1126/science.243.4887.57.

Ramanathan, V., Crutzen, P. J. Kiehl, D. Rosenfeld.(2001) Aerosols, Climate, and the Hydrological Cycle. www.sciencemag.org SCIENCE VOL 294, 2119-2124.

Ramanathan, V., Crutzen, P.J., Kiehl, J.T., Rosenfeld D., (2001a) Aerosols, climate and the hydrological cycle. Science 294, 2119-2124.

Rastogi, N., Sarin, M.M., 2007. Chemistry of precipitation events and inter-relationship with ambient aerosols over a semi-arid region in western India. Journal of Atmospheric Chemistry 56, 149–163. doi:10.1007/s10874-006-9047-5.

Rodhe, H., Herrera, R., 1988. Acidification in Tropical Countries, John Wiley, New York, 405p.

Rodhe, H., Langner, J., Gallardo, L., Kjellstrom, E., 1995. Global-scale transport of acidifying pollutants. Water, Air and Soil Pollution 85, 37-50.

Rosenfeld, D., Sherwood, S., Wood, R., and Donner, L., (2014) Climate effects of aerosol-cloud interactions; Science 343(6169) 379–380, https://doi.org/10.1126/ science.1247490.

Satheesh, S. K., Moorthy, K. K., Babu, S. S., Vinoj, V., and Dutt, C. B.S., (2008) Climate implications of large warming by elevated aerosol over India; Geophys. Res. Lett. 35(19), https:/doi.org/10.1029/2008GL034944.

Soni, V. K., Pandithurai, G., & Pai, D. S. (2016) Is there a transition of solar radiation from dimming to brightening over India? *Atmospheric Research, 169, 209–224.* doi:10.1016/j.atmosres.2015.10.010.

Spokes, L. J., Jickells, T. D., and Lim, B. (1994) Solubilisation of aerosol trace metals by cloud processing: A laboratory study, Geochimica et Cosmochimica Acta, 58, 3281–3287, 10.1016/0016-7037(94)90056-6.

Suvarapu LN, and Baek S-O. (2017) Determination of heavy metals in the ambient atmosphere: A review. Toxicol Indust Health 33:79–96. Rama, K., M.M. Sarin, P. Hegde (2008) Atmospheric abundances of primary and secondary carbonaceous species at two high-altitude sites in India: Sources and temporal variability. Atmospheric Environment vol. 42, pp. 6785–6796.

Turner, J., Lamberi, M. and Knoti', J. (1996) Nutrient Inputs From Rainfall In New South Wales State Forests Forest Research And Development Division State Forests Of New Soutii Wales Sydney. Research Paper No. 17.

Warrier, A.K., R. Shankar, B.R. Manjunatha, B.G. Harshavardhana (2014) Mineral magnetism of atmospheric dust over the southwest coast of India: Impact of anthropogenic activities and implications to public health. Journal of Applied Geophysics 102 pp 1–9.

Willeke, K., Whitby, K.T., (1975) Atmospheric Aerosols: Size Distribution Interpretation; J. Air Pollut. Control Assoc., 25 (5), 529-534.

Yang, D., Wang, M., Lu, H., Ding, Z., Liu, J., & Yan, C. (2019). Magnetic properties and correlation with heavy metals in mangrove sediments, the case study on the coast of Fujian, China. Marine Pollution Bulletin, 146, 865–873. doi:10.1016/j.marpolbul.2019.07.035.

Zan, J., Fang, X., Li, X., Yan, M., Kang, J. (2019). Long-term variations in the lithogenic susceptibility of Chinese eolian deposits since the late Pliocene. Geophys. Res. Lett. 46, 726–735.

List of Publications

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Jithin Jose, Naveen Kumar, A, Manjunatha, H.V., Krishnakumar, K.N., and B.R. Manjunatha (2019) Nanotechnological Applications for Understanding Atmospheric Pollution, Health Hazard and Paleoclimate. International Journal of Earth Science and Engineering (accepted for publication).

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Signature of the Student

Date……

Signature of the Supervisor

Date…….